

Techno-Economic and Environmental Analysis of Energy Scenarios in Ghana

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Abstract

The electricity potential in Ghana has become a huge challenge to the nation, which increases the country's economic growth and reduces Nation's development. The study highlights the trends on the power grid of the energy potential for the past ten years' impact regarding the directions on the power grid, and to determine the economic potential viabilities couples with the sustainability of renewable energy sources in Ghana. The study relied on substantial reviewed literature and revealed that Ghana's energy generation has passed through multiple stages, started from diesel generator supply systems owned by industries and factories to hydroelectricity, thermal power electricity powered by natural gas or crude oil, and solar electricity. The study showed that as of December 2017, Ghana had installed a total capacity of 4398.6 MW comprising Hydro, Thermal, and Solar Plants. Out of the full power, Hydro-power generates 1580 MW representing 35.9%, Thermal generates 2796 MW, which also represents 63.6%, while 22.6 MW capacity represents 0.5%. The Long-range Energy Alternatives Planning system (LEAP) tools were employed to consider three different scenarios: energy demand, cost-benefit, and carbon limitation. 2018 was considered as the base year and 2048 as the end year. The results show that 17,800 GWh was estimated as energy demand at base year while 44,000 GWh at end year of 7% annual growth rate. The share of renewable power plants was almost zero at the current account. The share of solar thermal plants may reach 90% due to direct cost and externalities. The study adopted one-hundred-year direct GWP at the point of emissions to compare the Mitigation (MITG) and Reference (REF) scenarios. The model indicated 1.3 Million tons of CO₂ saving and 4.0 billion U.S. dollars saving with a 5% discount rate in power generation until 2048, if only the country could afford to develop its generation system with the high deployment of RETs, additional benefits in the form of a sustainable safety environment and less emission carbon would be achieved in the next 30 years.

Keywords

Energy Demand, Mitigation (MITG), Reference (REF) Scenarios, Energy Potential

1. Introduction

Energy consumption has one of the most reliable indicators of the development and quality of life reached by a country. The necessity of satisfying forecasted energy demand for a given period is the foundation for energy generation planning [1]. As defined by the World Energy Council, power planning is that part of economics applied to energy problems was taken into consideration the analysis of energy supply and demand, as well as the implementation for ensuring coverage of energy needs in a national or international context (Dictionary 1992). Ghana faces energy challenges as the country struggles to meet reliability requirements. The country's electricity supply section of the country is characterized by power outages that have adverse implications on the quality of life and industrial infrastructure development. Stable energy is vital for the recent development oil and gas industry, which investors the expected oil and gas would be motivated by the economy shortly [2]. According to [3], access to electricity is a critical element in achieving economic development in every nation. Electricity is needed to maintain almost every activity, such as security, stability, production of goods and services, and economic infrastructure development. Developing a realistic generation analysis plan is crucial if the country achieves its medium to long-term development goals. Inappropriate analysis can result in frequent power outages where the generation capacities can only meet about 65% of the current demand [4]. Power generation in Ghana has gone through several phases, starting from diesel generator supply systems owned by industries to the hydro stage following the construction of the Akosombo dam. Thermal powered by natural gas or crude oil, and subsequently to renewable Solar [5].

The electricity crisis has become a challenge in Ghana. This challenge has reduced the country's economic growth and transformation as decline in industrial activity, job and income losses, and interruptions in social life because of this energy crisis are the instances of the right elements of what now seems like a hindrance on Ghana's developmental agenda. Thus, an unreliable and insufficient supply of power becomes even rampant due to the economic costs of inadequate power supply [6].

1.1. Brief History of Ghana's Energy Sector

Ghana's motivation to enter massive infrastructure development such as the industrialization of building roads, schools, hospitals, factories, and other equally essential facilities called for a reliable supply of power after the country succeeded in attaining independence. The country's energy sector led the country to

rely on mainly diesel generators owned by industrial establishments, including factories and mines, and other institutions such as hospitals and schools in the Gold Coast Era. The supply of electricity in Ghana, according to [2] started back during the colonial era (Gold Coast). The then Gold Coast Railway Administration established the first public electricity generation system in 1914 to supply electricity for the railway sector (ISSER, 2005). In 1947, the Electricity Department within the Ministry of Works and Housing was to take over electricity supplies from the Public Works Department and the Railways Administration. The primary source of the electricity supply system over this period was Diesel Generator Plants. The sector is revolutionizing with the development and completion of the Akosombo Hydroelectric Power Station, which also saw the export of electricity to neighboring countries, including Togo, Burkina Faso, and Benin [2]. The Akosombo Hydroelectric power station through a loan facility obtained from the World Bank and the USA. Volta River Authority (VRA) was subsequently established in 1961 and charged with electricity generation duties via the Volta River's waterpower. The completion of the Akosombo Hydroelectric power in 1965 yielded a total installed capacity of 1038 megawatts (1038 MW) for electricity generation. During this period, the significant electricity consumers were the Volta Aluminum Company (VALCO) and the National Electricity Distribution Company. In 1982, Kpong Hydroelectric Power Station was commissioned, increasing the installed generation capacity by 160 MW, indicating a gradual shift from generator plants to hydroelectricity. Besides, the Bui Hydroelectric power station was a commission to produce 400 MW in 2013. Concurrently, thermal power into the system; in the year 2000, the Takoradi Thermal power station was commissioned with 550 MW, followed by the Tema Thermal station, which produced 236 MW in 2008. In 2010, 200 MW was added after the completion of Son Asogoli power station while Kpone Thermals I & II completed in 2016 and 2017 respectively produced 230 MW and 340 MW as indicated in **Table 1** below. All is to boost the energy generation sector for better social life and smooth growth of all the economy segments. The 2016 projections from

Table 1. Energy generation in Ghana.

Power Station	Year	Type	Capacity (MW)
Akosombo Hydropower	1965	Reservoir	1038
Kpone Hydropower	1982	Reservoir	160
Bui Hydropower	2013	Reservoir	400
Takoradi Thermal PowerStation	2000	Light Crude oil/Natural Gas	550
Tema Power Station	2008	Diesel Fuel	236
SonoAsogoli Power Station	2010	Natural Gas	200
Kpone Thermal I Power Station	2016	Natural Gas	230
Kpone Thermal II Power Station	2017	Natural Gas, Diesel Fuel	340

Source: Modified from energy commission, 2018.

the Energy Commission indicate a marginal increase in the installed capacity of electricity. The review shows that most power sources will maintain their generating capacity in 2017 (**Table 1**). Given Ghana's historical dependency on hydro (with relatively unchanged generating capacities) and the grid power consumption, what troubling is the thermal plants and renewable plants (with relatively little addition to the generating capacity in 2017) to operate under capacity?

1.2. Energy Scenarios in Ghana

Electricity is the foundation of a functioning society [7], the significant determinants of the economic prosperity of a country. It plays a vital role in undertaking daily activities in the industrial and human life sectors [2]. With a growing population worldwide and increasing living standards, many countries struggle to provide enough electricity needed sustainably. This strain is evident in developing countries, affected by an ever-growing climate instability [8]. Over the past decade, Ghana's energy sector has suffered several power challenges resulting in an extensive economic situation [9]. The World Bank ranked electricity as the second most important constraint to business activities in Ghana. It further estimated that Ghana lost about 1.8% of GDP during the 2007 power crisis [2]. Also, the Institute of Statistical, Social and Economic Research (ISSER) at the University of Ghana in a 2014 report in their study that Ghana, on the average, lost production worth about the US \$2.1 million per day (or the US \$55.8 million per month) through the power crisis alone [10].

Notwithstanding that, Ghana has made significant strides in electricity access due to long-range energy planning with clear targets, external funding availability, political/popular demand, and the central Government's active role in implementing energy policies. By the close of December 2017, 4398.6 MW capacity had to comprise Hydro, Thermal, and Solar Plants. Out of the total capacity, Hydropower generates 1580 MW representing 35.9%; (thus, Akosombo: 1020 MW, Bui: 400 MW, and Kpone: 160 MW). On the other hand, Thermal power plants generate 2796 MW, represented 63.6%, while 22.6 MW capacity representing 0.5% by the Solar plants [4]. These reveal that the installed capacity in operational and available grid power supply at the end of 2017 was about 4398.6 Megawatt (MW). The 2016 projections from the Energy Commission indicate a marginal increase in the installed capacity of electricity. Data provided in **Table 2** represent a summarized nation's progress in energy scenarios shortly. The review shows that most power sources maintain their generating capacity in 2017 (**Table 2**). Given the historical dependency on Ghana's Hydropower (with relatively unchanged generating capacities) power consumption, there is a relatively significant downwards change in consumption by 8.5% in 2017. However, Thermal, and Renewable plants significantly increased by 22.7% and 36.1%, respectively, in 2017, indicating a gradual shift from hydropower plants. The expansion in both thermal and renewable power indicated above is partly correlated and proportional to the population growth of the country [4].

Table 2. Various scenarios and assumptions to reach targeted levels of electricity and LPG.

Scenario - assumptions	Likely achievable year
Electricity	
100% household access - business as usual	2023
100% household access to electricity - a minor shift in trajectory	2020
100% household access - a major shift in trajectory	2016
100% community access - Business as usual for communities with minimum population of 500	2016
LPG	
50% access to LPG - business as usual	2023
40% access to LPG - business as usual	2020
50% access to LPG - a major shift in trajectory	2020

Source: [1].

1.3. Economic Potential Viabilities of Energy Scenarios in Ghana

Investing in energy technologies like photovoltaics, hydro, thermal, and many others is capital-intensive in a developing country like Ghana [4]. However, the Government's effort to provide incentives like subsidies and create the economic environment for private sector investment can boost energy generation investment in Ghana. According to [9], it can help curb the recent power outages and load shedding, thereby increasing productivity and economic resilience. According to [11] argued that energy placement's capacity depends on a considerable portion of the initial financial investment prerequisite for power generation infrastructures deployment. The energy placement's economic success is related to its financial viability, which depends on the capacity generating power generating at a competitive cost. The Institute of the Statistical, Social and Economic Research (ISSER) in the year 2014, however, estimated Ghana to losses between \$320 million and \$924 million per annum in productivity and economic growth, which will affect gross domestic product (GDP) annually due to inadequate and unreliable power supply. (ISSER 2005) Thus, with the economic costs of inadequate power supply, a reliable and adequate supply of power becomes even more pressing. Currently, national energy policy has implemented a brief framework of the Government's policy direction, challenges, and actions, to aid with the operative management and development of the sector and provide the public with information about its policy goals. The policy addresses the low quality and unreliable supply of electricity and the utility company's poor financial performance and helps them raise the finance needed for infrastructure [12]. The solar project's development would be adequate if the internal Rate of Return (IRR) is equivalent to or greater than the required return rate [13].

2. Methodology

- This part of the study aims to evaluating and projecting the energy scenarios

in Ghana from 2018-2048. Long-range Energy Alternatives Planning System (LEAP) software was employed to consider three different scenarios: energy demand, cost-benefit, and carbon limitation. Scenarios are self-consistent of how an energy system might evolve over some time [14]. Using LEAP, policy analysts can create and evaluate alternative scenarios by comparing their energy requirements, social costs and benefits, and environmental impacts. In this study, the year 2018 was considered as the base, thereby projecting it through 2048 as the study pattern years. LEAP system was selected among others because it supports a wide range of different modeling methodologies: thus, on the demand section, these range from bottom-up, end-use accounting techniques to top-down microeconomic modeling. LEAP also includes a range of optional methodologies, including stock-turnover modeling for transport planning areas. On the supply side, LEAP provides a range of accounting, simulation, and methodologies that are powerful enough for modeling electric sector generation and capacity expansion planning [14].

- The Specific Objective was to develop the framework to evaluate the energy potentials in Ghana. These involve applying soft technique methodology guide to evaluate the power potential in Ghana using the Long-range Energy Alternative Plan (LEAP). LEAP is an integrated, planning energy modeling tool that can track energy consumption, production, and resource extraction in all sectors for the economy. The tool that can create models of different energy systems, where each requires its own unique data structures. LEAP is intended as a medium- to long-term modeling tool and is design around the concept of scenario analysis. This approach allows policymakers to assess an individual policy's impact and the interactions that occur when multiple policies and measures as study has been applied widely in many kinds of literature for scenario planning as the best scientific method to acquire knowledge.

2.1. Framework and Equations (Figure 1)

Step 1: Ask question:

The initial stage begins with ask questions to identify the main topic. This paper's main point was asking of the suitability for good integration of Renewable

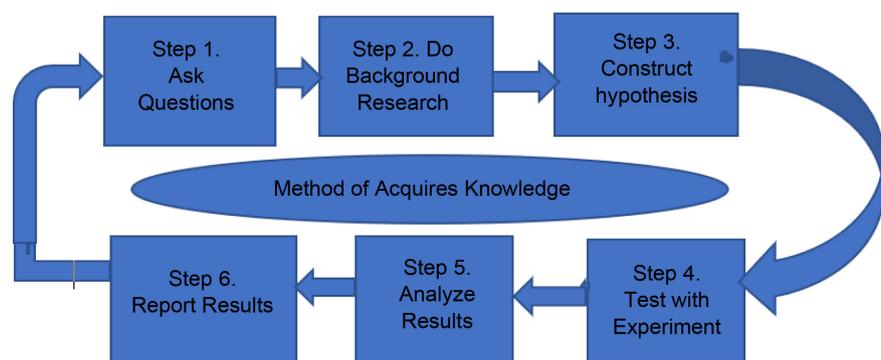


Figure 1. Framework development.

Energy Technologies (RET) in Ghana.

Step 2: Do background research:

This stage was seeking to find out the elements that would be enhance the results of the decision and the social, economic, political, and environmental. Examples of main variables that influenced the generation sector of Ghana include energy security and reliability, types of RET technologies, RET potential, the cost of fuel, technical capacity, and economic and population growth as energy demand.

Step 3: Construct Hypothesis:

Involves manipulating of data to identify data to be used, the most important elements from the manipulated variable, e.g., the points causing power Ghana's generation system.

Step 4: Test with experiment:

This involves of scenarios to be developed based on the manipulating elements exercise, the scenario was to develop the main point by adding details using the other factors. Involves making use of each main structure or trend of the manipulated elements to end up with policies to enhance the decision-makers.

Step 5: Analysis results draw conclusion:

This stage involves the scenario's methodology used in this paper involves the various calculations of growth for future generation development and procedures.

Step 6. Report results

The final stage involves writing of your contributions, checking the various errors involving Grammar and plagiarism.

2.2. Development of Ghana LEAP Demand Model

The demand model approach in LEAP was adopted for modeling the future energy demand in Ghana. The end-Use provides a detailed modeling account for sectors as well as end-users and energy-consuming devices and appropriate method when assessing the long-term transitions. The main factor for the development of future energy systems is the projection of demand, depends on the demographic and macroeconomic indicators of the study area. The reliable energy system should be matching the demand requirement. The Ghana population in 2018 was 29 million people projected to be increasing at a growth rate of 3% yearly may increase to 70.4 million in 2048. The LEAP software has three main program parameters, demand, transformation, energy resources, environmental estimates, and comparisons. The model uses indigenous data inputs as the main parameters. The energy demand for end-uses depends on demographic factors such as population growth, household size, and o others. The LEAP estimates the result of its activity about the level of the required energy and the intensity energy required. In determining the energy demand for the future, the software uses growth in GDP, population, and urbanization with the formula below:

$$D_{s,t} = TA_{Activity\ s,t} \times EI_{Activity\ Level\ s,t} \quad (1)$$

$$D_{s,t} = \sum_{s,t \times Activity} L_{s,t} \times (EIB_{L,t} - EI_{s,t}) \quad (2)$$

where S is the current scenario, BL is the baseline scenario, and t is the year. When cost is specified relative to the Current Accounts intensity

$$D_{s,t} = \sum_{t \times Activity} EL_{s,t} \times (EI_0 - EI_{s,t}) \quad (3)$$

D is the energy demand, TA is the total activity, EI is energy intensity, s is the scenario, and t is the year (ranging from the base year to the end year) [14].

$$S = Stock_{ty} \times Mileage_{ty} \times PE_{ty} \quad (4)$$

where S is the transport fuel demand ty , the $stock$ is the number of fuels existing each year; $mileage$ is the yearly distance duration per plant, PE is fuel consumed per unit of plant duration, t is the plant type, y is the year [15].

2.3. Electricity Demand Forecast in Ghana

Electricity consumption in Ghana varies between urban and rural areas. In 2017, 79.3% of the population had access to electricity in Ghana. The urban households had access to 39.8% electricity compared to 39.5% of rural households. With the current average population growth rate of 3% in 2018, which to increase to about 70.4% by 2048, the energy demand for domestic consumption has the potential to increase significantly by 2048. The 121 billion US\$ for GDP of 3% growth rate was adopted for base caseload projection from 2018 to 2048 whereby the GDP would be consumed 293.7 billion of 70.4%, with the electricity generation planning margin of 35% from 2018 to 2048 when the power supply would be increased by 90%. The energy intensity data used for model was employ from an energy consumption survey conducted by the Energy Commission of Ghana. 30-year analyses of the possible developmental and structure of the power grid system scenario for Ghana using LEAP expands from 2018 to 2048. The base year's choice was due to the data obtained from the Ghana Statistical Service and national energy survey by the Energy Commission from 2010 to 2017 provides reliable data for the model. The energy demand projection results from 2018 to 2048, using the LEAP energy demand model, are present in **Figure 2**. The results show that demand projection can increase with an average demand growth rate of 7% from 2018 to 2048. These growth rates followed the country's consistent official load projections in **Figure 3** further shows that the total energy requirement by 2018, 2030, and 2048 will be from 17,700 MWh and increase to 23,300 MWh through 43,200 MWh at the end of the study period mitigation scenario. The current installed capacity holds the potential to be increased from 15,000 GW to 34,000 GW to meet its future electricity requirement. The actual demand may be higher than the projection in this study, based on historical GDP values in which they may not reflect. The insufficient generation and low electrification rate in rural areas may suppress the demand when the demand is greater than the supply. Thus, the historical trends alone may not

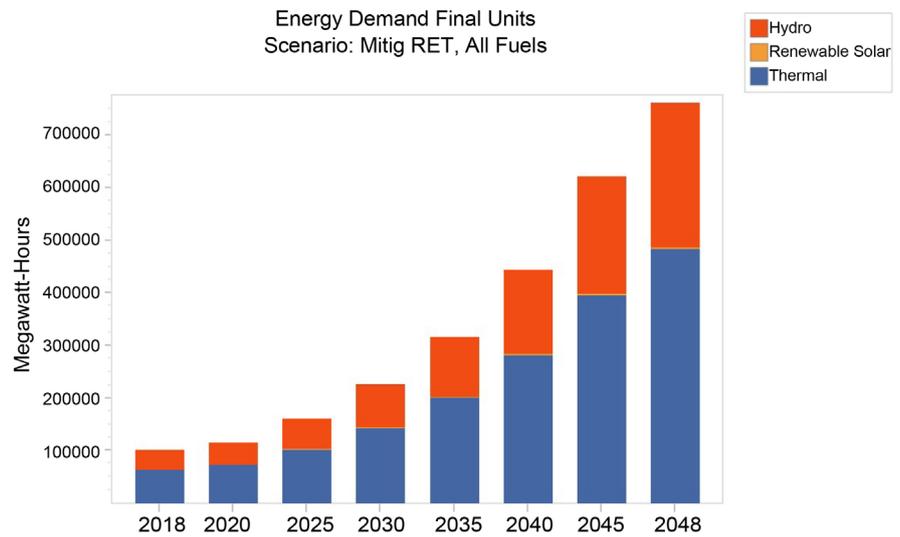


Figure 2. Electricity demand forecast for Ghana for 30 years.

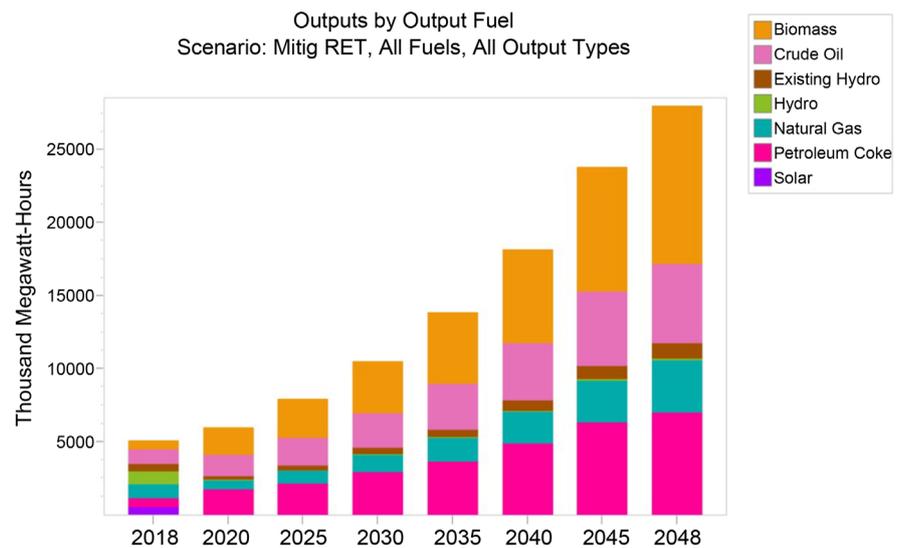


Figure 3. The outputs by output fuel.

fully capture the energy demand captured by back casting [2]. The electricity demand was calculated by LEAP for all the scenarios in which the technology cost data adopted from. The installed capacity on the current situations from the three plants Hydro, Thermal, and Renewable in the mitigation scenario as represented in Figure 3. The future year investment cost of the conventional energy systems in Ghana (Hydropower, Thermal power, and Solar) was assumed to be constant throughout the study period.

2.4. Cost of Consideration in LEAP

Table 3 shows the investment, fixed Operations and Maintenance (O&M), and variable O&M values considered in the LEAP model. The fixed Operation and Maintenance (O&M) is the part of the maintenance cost of a plant which does

Table 3. Review of the power of Ghana.

Generating Station/Plant	Fuel type	Installed capacity (MW)		Dependable capacity (MW)	
		2016	2017	2016	2017
Akosombo	Water	1020	1020	1000	900
Bui	Water	400	400	360	340
Kpong	Water	160	160	148	140
<i>Sub Total Hydro</i>		1580	1580	1508	1380
TAPCo	NG	330	330	300	300
TICo	NG	340	340	320	320
SunonAsogli	NG	380	560	350	520
CENT	NG	220	110	200	100
Thermal 1 (TT1PP)	NG	126	110	100	100
Thermal 2	NG	50	80	45	70
Kpone (KTPP)	NG	126	220	100	200
Kar power ship	NG	80	470	70	450
Ameri Plant	NG	250	250	240	230
AKSA	NG	225	260	220	220
Trojan	NG	25	44	22	40
Genser	NG	20	22	18	18
<i>Sub Total Thermal</i>		2172	2796	1985	2568
Safisana	Solar	2.5	0.1	1.5	0.1
VRA solar	Solar	20	2.5	10	2
BXC solar	Biogas	0.1	20	0.1	16
<i>Sub Total Renewable</i>		22.6	22.6	11.6	18.1
Total		3774.6	4398.6	3304.6	39,661

Source: modified from energy commission, 2020.

not depend on the operation of the plant, thus, include property tax and insurance, planned and unplanned maintenance, administration, operation staff as well as re-investments within the scheduled lifetime 30 years duration. The actual (O&M) cost estimated by the percentage rates from National Renewable Energy Laboratory (NREL) and data for power generation technologies rates, the prices of fossil fuel resources are to predict because of its high price in the world market. However, the benchmark fuel price was considered the most reliable assumptions and adopted from energy commission.

2.5. Fuel Prices Used in the Model in Ghana

To model, the feedstock fuel for the thermal plants considered in the Ghana LEAP model, the actual crude oil and natural gas prices were made available for power generation in Ghana for the reference years, from 2018 to 2048. The price was adopted from [16]. Transportation and taxes were estimated using the

growth rate of 3% and 35% for crude oil and natural gas to reflect the current price trend. Ghana has no known coal reserves, therefore assume that all coal will be import. The coal price projections on the scenario transportation, taxes, and processing charges were 35%.

2.6. Modelling the Energy Scenarios in Ghana

The installed capacity of Ghana in 2018 was 4398 MW consisting of a hydro capacity of 1580 MW, 2760 MW contributed from ten thermal power plants, and renewable of 22.6 MW. To evaluate the energy potentials system in Ghana, the various generating plants were aggregate. The implication is that the recycle plant represented the existing electricity plant, namely hydro, thermal, and renewable plants modeled to representing the Mitigation and Reference systems. The plants' operational characteristics in modeling the generation system from 2018 to 2048 are present in **Table 4**. The data in **Table 5** were from actual plant operational data obtained from the energy outlook by using Ghana from [16]. Most of the thermal plants in Ghana were designed to operate on light crude oil and natural gas. Natural gas is the preferred fuel when available because of its relatively low cost and minimal environmental impact conditions. The feedstock ratio of 35% NG and 57% light crude oil were assumption for 2018 to 2048. The interpolated 90% and 35% for natural gas and light crude oil by respective outputs fuel considered in **Table 6**. Among the three-fuel construct, NG seems to increase at a relatively realistic interval consistently. The cost of NG compared to crude oil and coal seems a bit higher in the study period. Crude oil was relatively low at US dollars 86.6, NG US dollars 106.6, and Coal US dollars 96.8, yet the cost difference between coal and crude oil remains US dollars10.2 while the NG

Table 4. Operational characteristics of generation plants Installed capacity (MW) Scenario in Ghana.

Plant	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040	2042	2044	2046	2048
Hydro	1580	1676	1778	1887	2001	2123	2252	2390	2535	2690	2854	3027	3212	3407	3615	3835
Thermal	2796	2966	3147	3339	3542	3758	3986	4229	4487	4760	5050	5357	5684	6030	6397	6787
Solar	23	24	25	27	29	30	32	34	36	38	41	43	46	49	52	55

Table 5. Cost data considered in LEAP.

Technology	Fixed (O&M)		Variable (O&M)		Investment Cost	
	Million	US\$/MW	Million	US\$/MWh	Billion	US\$
	2018	2048	2018	2048	2018	2048
Hydro	22	39.84	25	45.28	115	300
Thermal (NG)	23	41.66	20	36.3	126.96	300
Solar	10	18.1	21	38.04	18	26.1
Biomass	34	61.59	39	70.64	102.30	216.19
Crude Oil	20	36.32	30	50.2	77	152.15
Petroleum Coke	25	45.28	35	63.40	105.6	180.8
Existing Elect	21	38	43	77	63	114.1

Table 6. Units: GWh, Operational characteristics of generation plans in Ghana.

Plant	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040	2042	2044	2046	2048
Hydro	35.9	41.1	47.1	53.9	61.7	70	80.9	92.6	106	121.3	138.9	159	182	208	238	273.3
Thermal	65.6	72.8	83.4	95.4	109.3	125.1	143.2	164	187.8	215	246.1	281.8	322	369	422	484.1
Solar	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.3	1.5	1.7	1.9	2.2	2.5	2.9	3.3	3.8

and crude oil were US dollars 20. However, the price difference between coal and the NG was US dollars 9.8, indicating a relatively lower comparatively. The onus lies on the management to make a clear decision about the choice to make.

3. Results and Discussions

The outlook of energy balance for Ghana under the various policies presented in **Figure 4** observed that the installed capacity needs to be increased to at least 3200 MW to meet the actual demand and specified reserved margin. Also, installed capacities of Mitigation Scenarios (MITG) will be required for the Mitigation scenarios. Due to limited capacity in the renewable section, the scenario considered in (MITG) capacity in RET scenarios confirmed that higher Ref RET needs to be able to match the same demand as that of the thermal plants. The MITIG RET deployment is meant to ensure a high diversity of generation mix with a reduction of the thermal plant share of generation.

3.1. Cost Analysis

The results of the scenarios expressed in the 2018 US dollars rate presented in **Table 5**, investment cost includes both fixed O&M and variable O&M. The generation of power from plant fuel leads to the emission of Greenhouse gases (GHG) influence society. The cost of these negative values, therefore, needs to be considered when assessing generation technologies. Currently, Ghana does not have a carbon tax in place; however, the study assumes a \$15 /ton carbon tax in 2018 is up to 2048. Revenue from the sale of electricity was captured in this analysis presented in **Table 6**. It observed from **Table 7** that, the Outputs by feed stock fuel installed capacity needs to be increased to at least 3200 MW to meet the actual demand and specified reserved margin while outlook of energy balance for Ghana under the various policies presented in **Table 8**. The electricity demand is estimating to all the scenarios modeled to meet this demand well cost-benefit summary in **Table 9** expresses only the avoided transformation costs. These results may not indicate the exact cost values for the scenarios; however, they provide a useful benchmark for comparing their economic performance. This is observed from **Table 6** that the capital and operational and maintenance O&M costs of the alternate MITIG scenario are higher than the Ref scenario. At the reference discount rate (5%), an extra \$607 and \$1278 Billion in capital investment will be required to implement the MITIG scenario and Ref RET scenarios over the 30-year study plan duration. These results were not surprising considering the higher investment cost of technologies considered in the alternative scenarios.

However, it observed that the total Net Present Value (NPV) of the Ref RET scenarios were lower than the MITIG scenario. This simulation shows the savings in the fuel cost that occur in the two RET scenarios. These results show that Ghana’s current generation system plan Ghana (Mitigation scenario) is obviously given when consideration is given to only investment cost. The actual availability of fuel cost by the alternative scenarios over the study period of 2018 to 2048 increasingly makes the higher integration of RET into the generation plan a viable alternative. The trend in cumulated discounted cost/benefits of the scenarios over the study period is illustrated in **Table 9**. The results in **Table 9** shows that economic benefits due to savings in fuel cost could be achieved within the long term with MITIG’s introduction of renewables. However, the Ref RET scenario will begin to yield economic benefits beyond 2048. RET can be deployed into the Ghana generation mix on their merit when consideration is given to their long-term benefits base on the assumptions and constraints used in developing the scenarios. **Table 4** further compares the NPV of the alternative scenarios under discount rates of 5% and 10%. The observation of the trend in

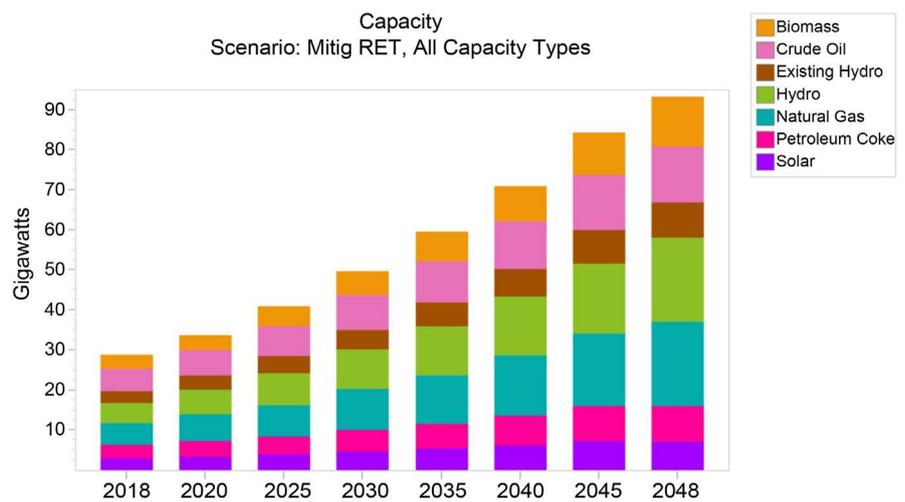


Figure 4. The installed capacity.

Table 7. Outputs by feedstock fuel, unit: thousand megawatt-hour fuel.

	2018	2020	2025	2030	2035	2040	2045	2048
Hydro	323	25	33	45	59	79	107	139
Natural Gas	515	605	790	1071	1490	1983	2677	3348
Solar	3	4	5	6	8	10	13	14
Crude Oil	1190	1492	1877	2449	3145	4123	5492	6450
Biomass	1617	1884	2448	3305	4346	5824	7906	9849
Exiting Hydro	12	240	299	386	492	640	846	962
Oil Product	1385	1606	2007	2600	3475	4500	5931	6594

Table 8. Energy balance information for province.

Units; Thousand Gigawatt-Hour	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048
Production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Imports	425.4	458	475.8	506.8	539.4	559.1	584.7	628.4	651.1	691.1	714.2
Exports	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.2	-0.2	-0.2	-0.2
Total Primary supply Electricity	425.3	457.9	475.6	506.7	539.3	559.0	584.6	628.2	650.9	691.6	714.2
Oil Prices	-138.0	-151.6	-153.4	-163.8	-177.0	-179.1	-183.1	-204	-206.9	-222.2	-227.1
Elect Generation	-257.4	-275.4	-290.4	-309.7	-327.6	-343.9	-363.9	-385.2	-403.3	-427	-442.7
Trans & Distribution	-0.1	-0.1	-0.1	-0.1	-0.1	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
Total Transformation	-395	-427	-443	-473	-504.8	-523.2	-547.2	-589.4	-610.4	-649.4	-670
Household	29.4	30.3	31.2	32.4	33.8	35.2	36.6	38.2	39.8	41.5	43.2
Plant Installed capacity	0.4	0.4	0.4	0.5	0.5	0.5	0.6	0.6	0.7	0.7	0.8
Total Demand	29.8	30.7	31.6	32.9	34.3	35.7	37.2	38.8	40.4	42.2	44
Unmet Requirements	-0.1	-0.1	-0.1	0.0	-0.2	-0.1	-0.2	-0.1	-0.1	0.0	0.0

Energy Balance, Units; Thousand Gigawatt-hour, MITIG Scenario 2018-2048 of 5% discount rate.

Table 9. The discount cost benefits 2018 to 2048 comparing of mitigation and reference scenario.

Cost (Millions\$)	5% Discount Rate		10% Discount Rate		15% Discount Rate	
	MITIG	RRF	MITIG	REF	MITIG	REF
Transformation	-5,598,744	5,598,744	26,082,691	-264,082,691	-260,580,309	-260,580,309
Trans & Dist.	296,620	-296,620	164,301	-164,301	98,814	-98,814
Electricity Gen	181,715,203	-181,715,203	99,434,244	-99,434,244	59,348,999	-59,348,999
Coal	865	-865	3775	-3809	3495	-3495
NPV	176,413,944	-176,413,944	125,685,011	-363,685,045	-201,129,001	-320,031,617

Discounted cost benefits 2018 to 2048 relative mitigation and reference scenarios.

NPV seems to suggest that the choice of discount rate does not significantly affect the choice of the alternative scenario compared to the base case as a similar trend was observed. However, an analysis in terms of the cumulative NPV compared to the MITIG RET clearly shows the lower discount rate, the higher the present value of the future cash flows. It is observed from **Table 4** that the lower discount rate of the RET scenarios is dominated by high capital-intensive technologies. A key priority should be geared towards the provision of guarantee long-term finance to promote the high integration of RET. The cost of fossil fuel was considered the most critical parameter that influences the cost of generating thermal plants, while that of RET is mostly dependent on investment cost. These two parameters also have high variability in the price: while the cost of RET, es-

pecially wind and solar, has seen a downward trend in capital cost that of the fossil fuel price is generally unstable. To this end, sensitivities on the capital cost of RET and the cost of fossil fuel were undertaken to determine the effect of variation of these parameters on the scenario's economic performance.

3.2. Environmental Evaluation

The total amount of Greenhouse Gas emissions (GHG) by each scenario is estimated and presented in **Table 10**. The results proved that by running optimization scenarios, Ghana could save approximately 1.32 million tons of CO₂ equivalent at the end of 2048 compared to applying only thermal power plants.

Based on the Fourth Assessment Report (AR4) One hundred-year GWP factors that were in line with IPCC's 2015 conference (COP 21) in December 2015, 195 adaptation recommends that as of 2018, national communications should use the AR4 factors to ensure uniformity in reporting. The cumulative one-hundred-year direct GWP at point of emissions of the scenarios compared to the MITIG and Ref RET scenario is presented in **Table 10**. The environmental effect of the introduction of coal on the environment is eventually the higher emission of the coal scenario compared to the cleaner natural gas generation.

The only difference between the MITIG and Ref RET scenarios is the endogenous references of the benefits at 5%, 10%, and 15% discount rates and carbon emission, the shear of the thermal power plants will be reduced in 2048, while the total cost of REF would be in the new MIGIT coal plants resulted in a cumulative non compare emission of about 40.1 million metric tons CO₂ equivalent without the compares. Although GHG savings are higher in the Ref RET than in the MITIG results in base net higher benefits at 5%, 10%, and 15% discount rates, that the cost of avoided CO₂ does not apply to the coal scenario since it resulted in higher emission compared to the MITIG RET. The results show that Ghana could secure funding through the Clean Development Mechanism (CDM) under the Kyoto protocol if the country makes maximum use of its abundant renewable energy potential. The annual fossil-fuel CO₂ emissions uncertainty estimates from 1950-2013 provided in this database derives from time series of global, regional, and the national fossil-fuel CO₂ emission This gridded uncertainty includes uncertainties contributions from the spatial, temporal,

Table 10. Cost of avoided CO₂ emissions (US\$/ton of CO₂ eq).

COST	5% DISCOUNT		10% DISCOUNT		15% DISCOUNT	
Env & Ext (Million US\$)	6.1	-6.1	2.2	-2.2	0.9	-0.9
Scenarios Compared	MITIG	REF	MITIG	REF	MITIG	REF
GHG Saving (Million Ton CO₂e)	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3
Avoided GHG's US\$/Ton CO₂e	n/a	4002 × 10 ⁶	n/a	2068 × 10 ⁶	n/a	1173 × 10 ⁶

proxy, and magnitude components used to create the magnitude map of FFCO₂ emissions. Throughout this process, when assumptions were judgment to employed, the general tendency in most cases was toward increasing the magnitude of uncertainty. Carbon dioxide (CO₂) is the mostly common greenhouse gas produced by anthropogenic activities, accounting for about 60% of the increase in radiative forcing since pre-industrial times [13]. By the largest source of CO₂ emissions is from the oxidation of carbon when fossil fuels are burned, which accounts for 70% to 90% of total anthropogenic CO₂ emissions. When fuel burned, most carbon is emitted as CO₂ immediately during the combustion process. Some carbon released as carbon monoxide, methane, or non-methane hydrocarbons, which oxidized to CO₂ in atmosphere within a period from few days to 10 - 11 years [17]. Ghana is among the country have no enforcement of CO₂ emissions limitation on power generation plants. The comparatively lower emission levels in the country because of the relatively low emission factors have informed the continuous expansion of thermal plants as represented in the Mitigation RET case scenario. The Ref RET was presenting the list of possible candidate plants will lead to higher emission levels in the country then contribute of coal generation plants to global GHG emissions.

Although the GHG, coal ash, which is a solid waste produced after combustion, the adoption of the coal scenario will therefore be at the expense of the environment. The country needs to consider the introduction of emission standards with the liberalization of the energy sector to encourage independent power producers to not only invest in renewable power but to continue to explore more efficient thermal generation such as Reference RET plants. **Table 7** further confirms the general idea of the contribution of renewable energy technologies in the reduction of CO₂ emissions. The results show that if the country could afford to make the possible Ref RET scenario into reality, about 4002 million metric ton CO₂eq should avoid over the study period, a reduction of about 35% to the Ref RET case plan. However essential to further analyze the environmental effect of the high introduction of biomass generation considered in higher capacities in the RET scenarios.

Environmental results in LEAP are also optimizing in terms of the cost of avoided 144.4 million CO₂ emission. The cost of CO₂ avoided is the cost of reducing CO₂ emission to the atmosphere expressed as \$/ton of CO₂ not emitted concerning the base case scenario. The decision criterion is to identify the least-cost alternative in reducing a ton of CO₂.

4. Conclusion and Recommendations

- This paper seeks to analyze the techno-economic and environmental conditions of the energy situation in Ghana. This study explored several policy options to meet Ghana's demand for electricity requirements based on available energy resources and technologies as the study revealed that Ghana stands the great potential to expand its electric power source to Renewable Energy

Technologies (RET). This study would ensure an efficient and sustainable supply of electricity in Ghana to meet energy requirements soon, thereby eradicating power outages in the country gradually.

- This study suggests that if the country could afford to develop its generation system with the high deployment of RET, additional benefits in the form of carbon trading could be achieved.
- These findings conclude that if the country could afford to develop its generation system with the high deployment of RET, additional benefits in the form of carbon trading under the Kyoto could be achieved; this will have significant implications for further development of renewables with the availability of funds which is the immediate implementation of these technologies to eradicate the electricity phenomenon in Ghana.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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